# Introduction to Agent-Based Modelling: Session 1

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QUEEN'S UNIVERSITY BELFAST

COMPLEX SYSTEMS AND NETWORK SCIENCE FOR PREVENTION AND CONTROL OF NONCOMMUNICABLE DISEASES
A WHO COLLABORATING CENTRE FOR RESEARCH AND TRAINING

GroundsWell
Transforming our cities from the ground up

# Session 1 training objectives:

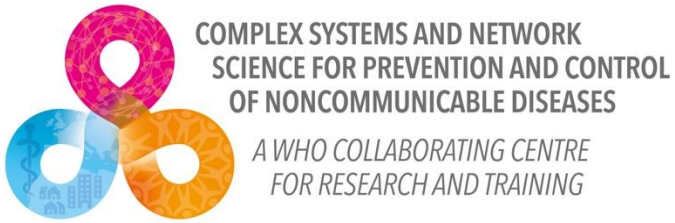
1. To introduce the concepts of agent-based Modelling.

2. To highlight tools, software and core texts for using and applying Agent-based models.

# Outline of session 1

| |
|---|
| Introduction to the WHOCC (10 min) – Leandro |
| Foundations of systems thinking (15 min) – Leandro |
| Foundations of agent-based modelling (15 min) – Sophie |
| Q & A (10 min) |
| Comfort break (5 min) |
| Planning for an agent-based model (15 min) – Leandro |
| Q & A (5 min) |
| Steps for building an agent-based model (15 min) – Sophie |
| Q & A (15 min) |

# Introduction to the WHOCC

COMPLEX SYSTEMS AND NETWORK SCIENCE FOR PREVENTION AND CONTROL OF NONCOMMUNICABLE DISEASES

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## Support the WHO in:

- **building capacity** in the application of complex systems and network science by offering training
- research involving the **application** of complex systems and network science approaches in NCD prevention and control
- development and provision of an online tool for undertaking **stakeholder network analyses** to support implementation research

## Members:

- Ruth Hunter, public/planetary health
- Neil Anderson, computer science
- Mike Clarke, evidence synthesis
- Leandro Garcia, complexity science
- Frank Kee, public health medicine
- Ciaran O'Neill, health economist
- Niamh O'Kane, complexity science
- Sophie Jones, complexity science
- Roisin Corr, administrator









## The WHO Regional Office for Europe

The World Health Organization (WHO) is a specialized agency of the United Nations created in 1948 with the primary responsibility for international health matters and public health. The WHO Regional Office for Europe is one of six regional offices throughout the world, each with its own programme geared to the particular health conditions of the countries it serves.

## Member States

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Sweden
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Uzbekistan

**53 countries**

**Work mainly eastern European including Albania, Armenia, Azerbaijan, Bulgaria, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Lithuania, Poland, Romania, Russia, Tajikistan, Ukraine, Uzbekistan**

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- Training: https://www.qub.ac.uk/sites/who/training/

- To date, over 1000 people have taken part in our training

# Further information


https://www.qub.ac.uk/sites/who/

# Keep in touch

**WHO Collaborating Centre for Research and Training on Complex Systems and Network Science for NCDs**

A WHO Collaborating Centre to build capacity in systems science skills, and to formulate innovate ways to address NCDs.

[Host LinkedIn page]

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**Member group: WHOCC for Research and Training on Complex Systems and Network Science for NCDs**

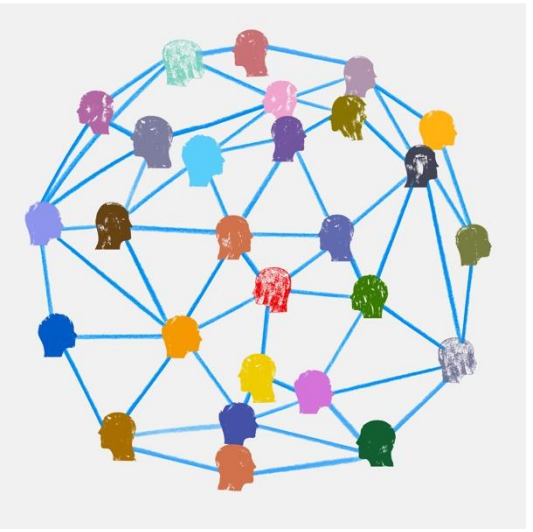
Private Listed

[Member only LinkedIn group]

[whocc@qub.ac.uk]

# Foundations of systems thinking

# Systems thinking in public health



# What is systems thinking?

- Way of thinking and doing based on systems concepts and methods
- **Core principle:** breaking the system down to its parts does not allow us to fully understand the whole system
- Active focus on structures, interconnections, processes, mechanisms, and context
- It is about seeing the ‘bigger picture’

# What is a system?

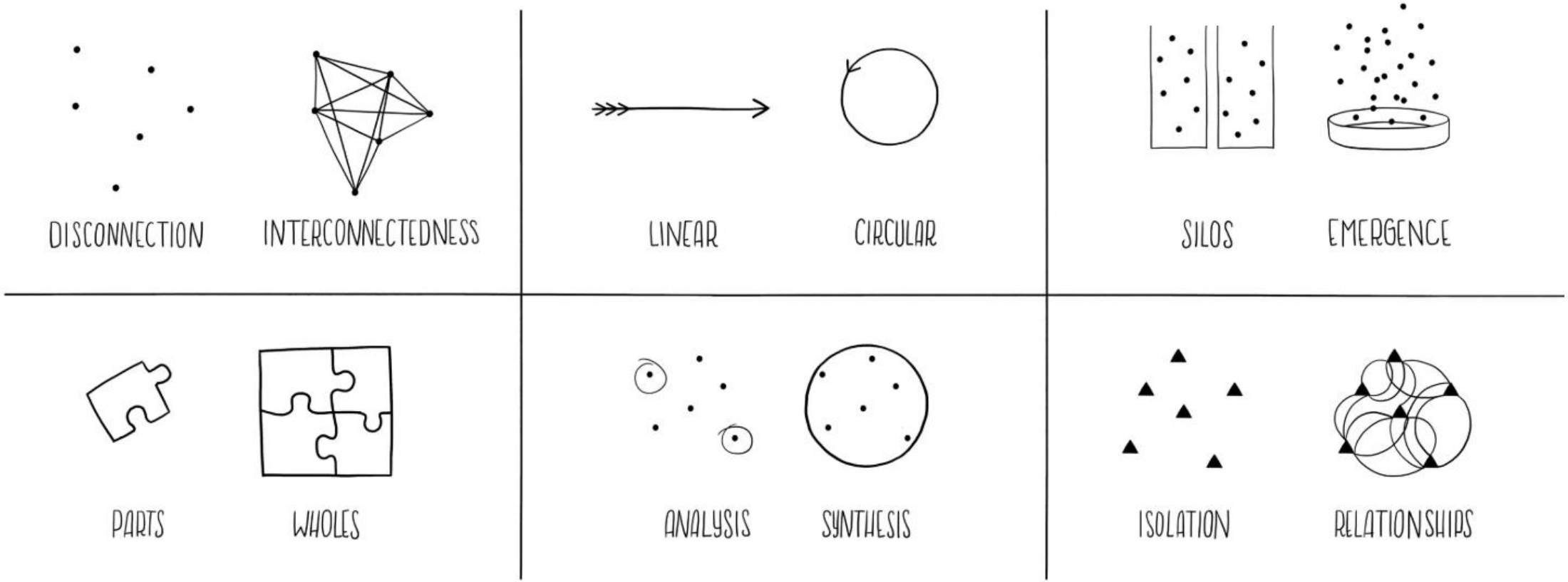
**Integrated whole (defined by the observer)**

- With structure (interconnected parts)
- New behaviour(s) at the system’s scale
- Porous boundaries (interaction with context)

**The system's structure determines its behaviour**
***(system as cause)***

# A system’s boundaries is given by the observer


# Mindset of a systems thinker




https://medium.com/disruptive-design/tools-for-systems-thinkers-the-6-fundamental-concepts-of-systems-thinking-379cdac3dc6a

# Why use systems thinking?

- Investigate systems problems
- Identify ways to address systems problems
- Broadening perspectives

# Why systems-based public health?

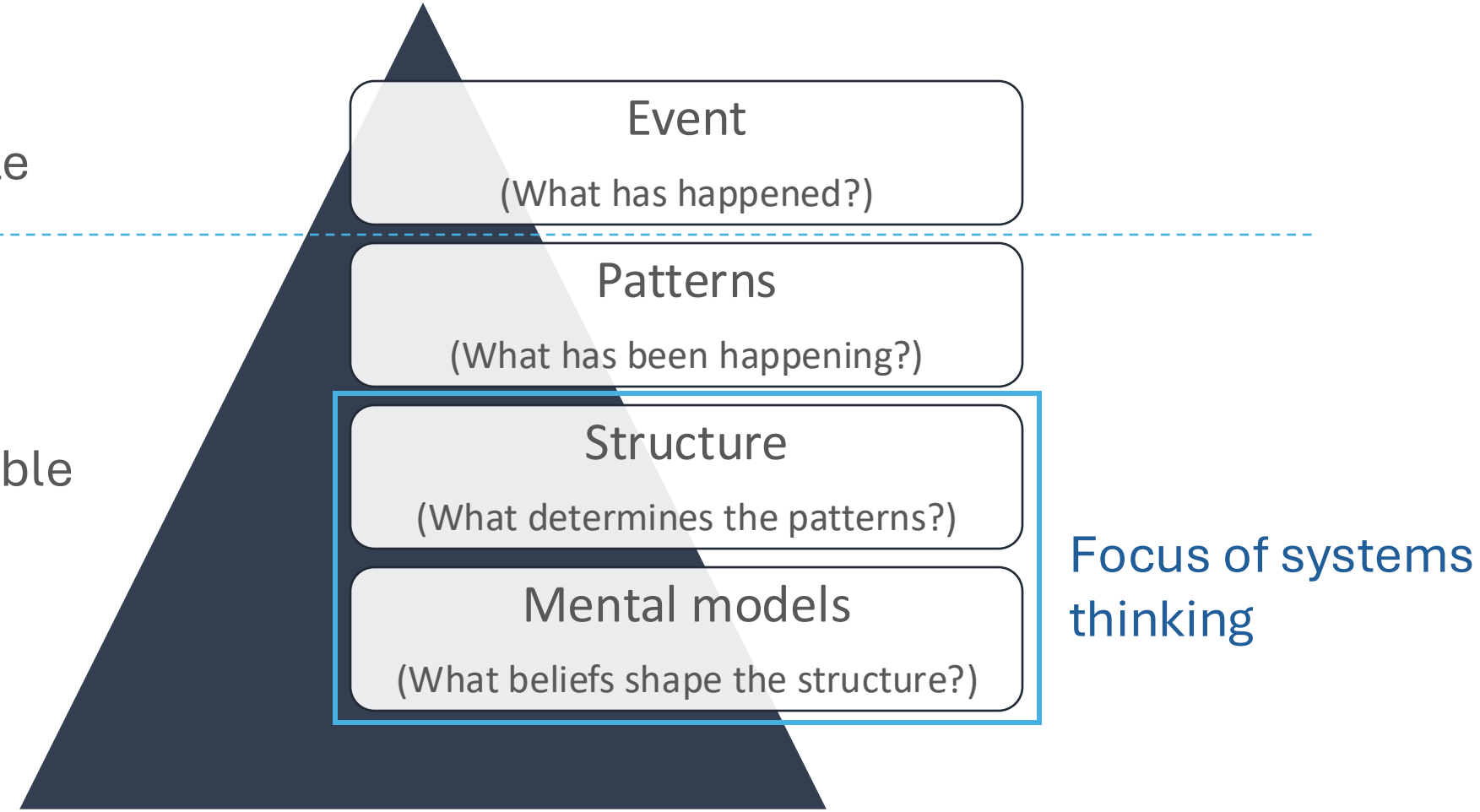
**Proposition:** Modern societies are complex systems

**Implication 1:** Many public health challenges emerge from how modern societies (complex systems) are organized

**Implication 2:** Interventions are actions within a complex system

What is visible

What is invisible

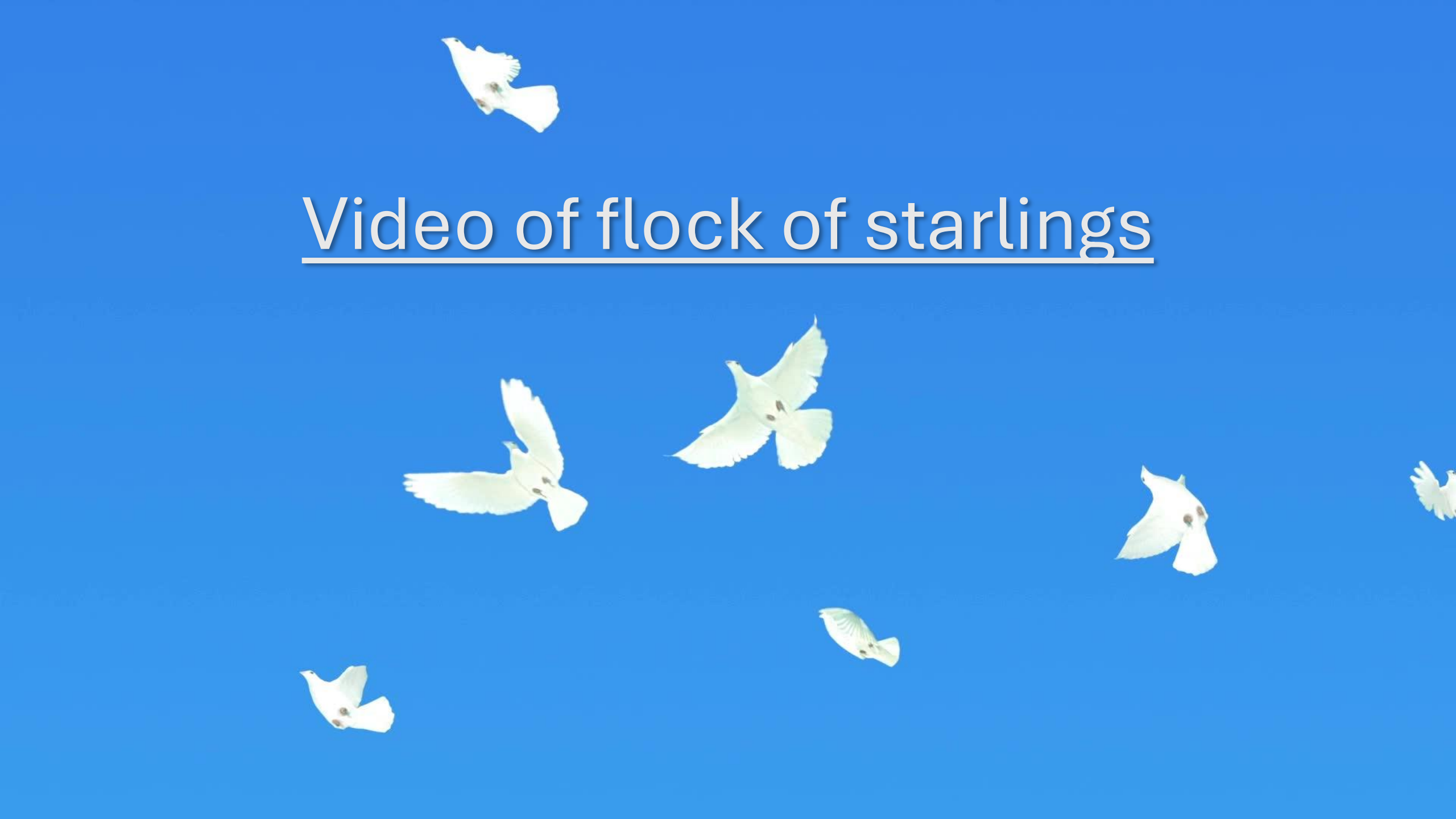



Focus of systems thinking

“Instead of asking whether an intervention works to fix a problem, we should aim to identify if and how it contributes to reshaping a system in favourable ways.”

Rutter H et al. The need for a complex systems model of evidence for public health. Lancet. 2017;390(10112):2602-4.
https://durmonski.com/self-improvement/iceberg-model-systems-thinking

# Foundations of agent-based modelling


Video of flock of starlings

# Flocking model

NetLogo Web: Flocking or NetLogo model library

- The birds follow three rules
  - “Alignment”: a bird tends to turn so that it is moving in the same direction that nearby birds are moving
  - “Separation”: a bird will turn to avoid another bird which gets too close
  - “Cohesion”: a bird will move towards other nearby birds (unless another bird is too close)

- When two birds are too close, the “separation” rule overrides the other two

# What is agent-based modelling?

Computational modelling technique for simulating the actions and interactions of autonomous entities to understand the behaviour of a system

**Key tenet:** *agent-centric perspective*, i.e., causal mechanisms of the system's behaviour are expressed by rules representing processes by which the simulated entities make decisions and act

# Agent-centric perspective

"I, the agent, have certain characteristics and beliefs of my own as well as information about the world around me, and therefore will do some action."

How do agents make decisions and behave to enact the process of interest?

Set of programable rules defined by the modeller

Badham J et al. Health Place. 2018;54:170-7.

# Example

**System:** A busy highway
**Agents:** Drivers

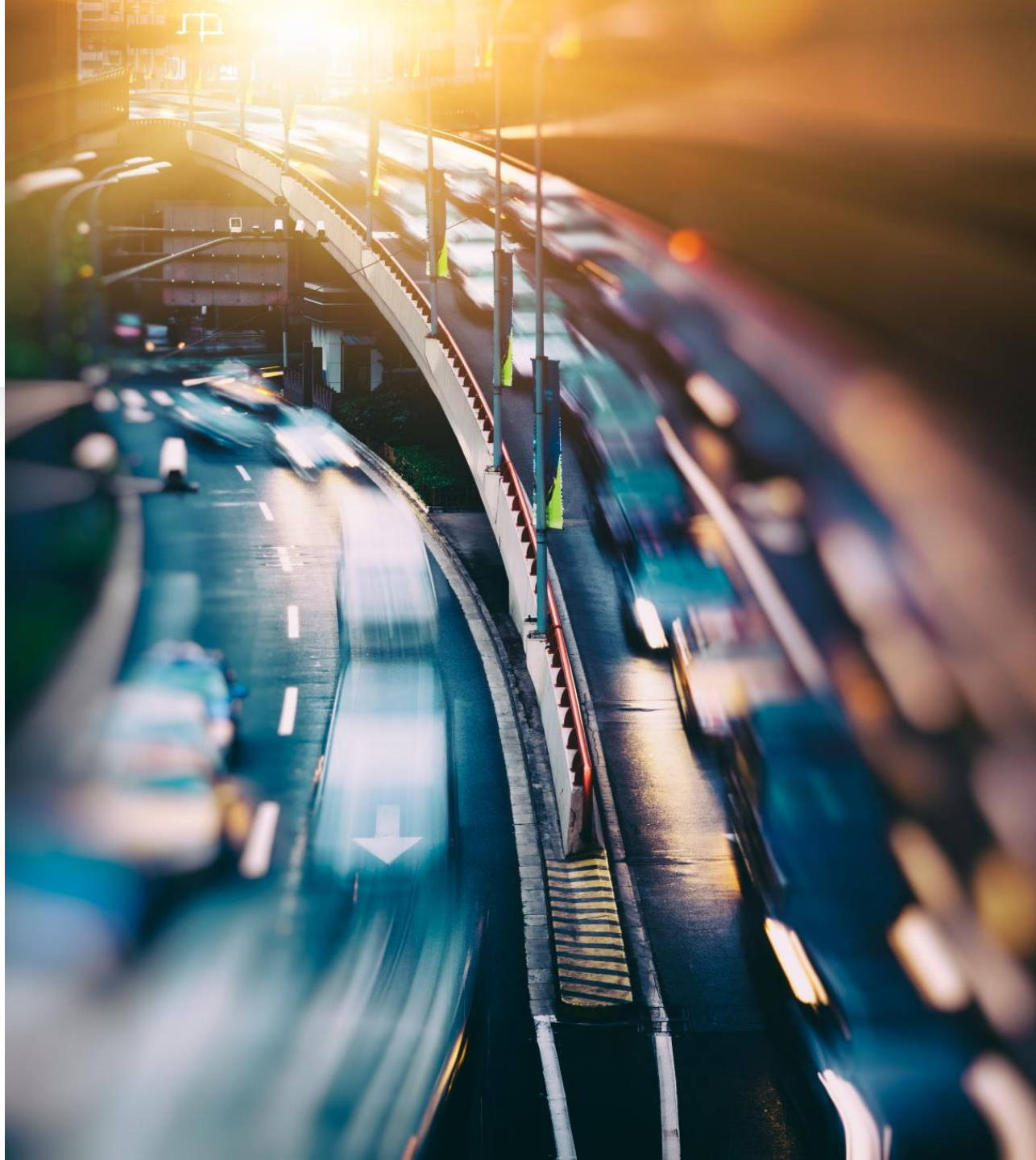
**Rules:**

- Keep a safe distance.
- Slow down if the car ahead slows.
- Change lanes if there’s enough space.

**Interactions:**
Drivers constantly adjust their speed and position based on nearby cars.

**Emergent behaviour:**

- Smooth traffic flow can suddenly slow down or stop for no obvious reason.
- Small actions (like one driver braking) can ripple through the system.



# Example

**System:** Disease spread
**Agents:** People (autonomous individuals)

**Rules:**

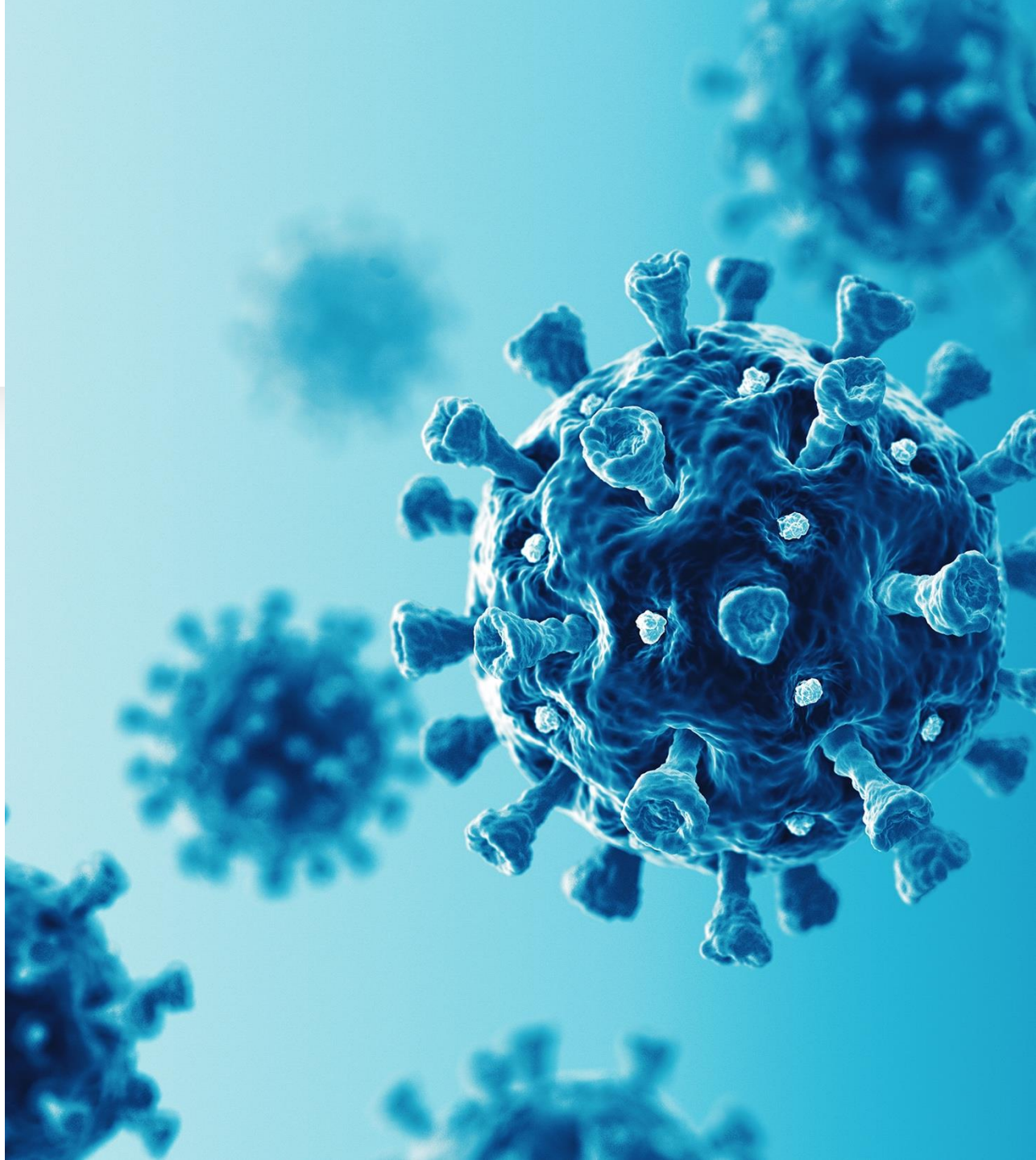
- If I meet an infected person, I might catch the disease.
- If I'm infected, I might isolate after a few days.
- If I recover, I can't be infected again.

**Interactions:**
People move, meet, and pass infections through contact.

**Emergent behaviour:**

- Infections rise and fall in waves.
- Clusters appear in crowded areas.

Changing rules (e.g., distancing or vaccination) changes system outcomes.



# Elements of an agent-based model

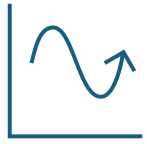
- Agents
  - E.g., persons, families, businesses
  - Numerous, heterogenous, and autonomous
  - Interdependent and reactive
  - Governed by a set of rules (defined by the modeller)
    - Sometimes can learn and adapt rules
- Space where the agents exist
- Set of rules that define how:
  - Agents evolve over time (“take decisions” and “behave”)
  - Environment changes over time
  - Agents and environment interact with, and react to, each other

# Agent-based modelling is useful when

- Each entity in the system is autonomous (and potentially different)
- Entities can react, learn and adapt
- Interactions between entities are heterogenous and critical to understand macroscopic properties and patterns
- Representation of environment is fundamental

# The main shift in thinking

## Regression-based models



Focus on dependent and independent variables

What variables do I need to consider?

## Agent-based models

Focus on dynamic processes

What processes do I need to consider?

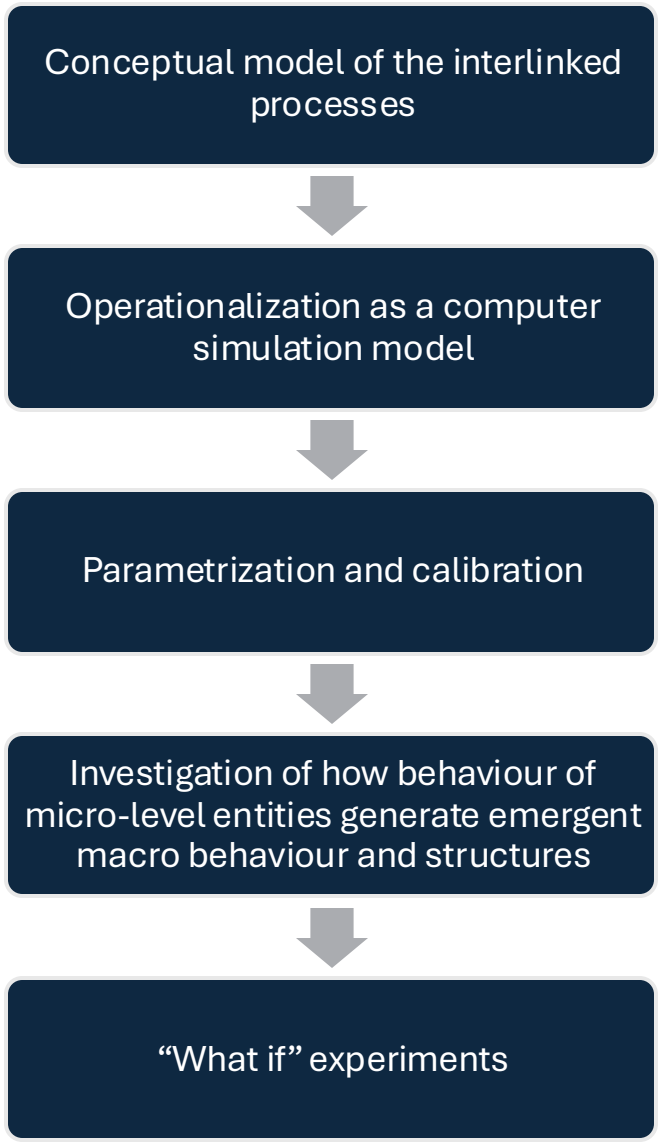
# Break

# Planning for an agent-based model

# Planning an ABM

1. Which processes should be simulated?
2. How to identify the characteristics and relationships relevant to each process: observations, literature, experiments, interviews…?
3. What agents are needed to implement the process?
4. What characteristics of agents are relevant to the process? (this includes characteristics that affect decisions, actions, and state indicators)
5. What form does the environment take: abstract space, realistic space, social network…?
6. What environmental characteristics influence the processes or are affected by the processes?
7. How do agents and the environment interact? (this includes inputs for actions and consequences of actions)
8. How to operationalize the processes? (details of the model rules that must be translated into code)

# What a work plan (normally) looks like




# Steps for building an agent-based Model: a practical example

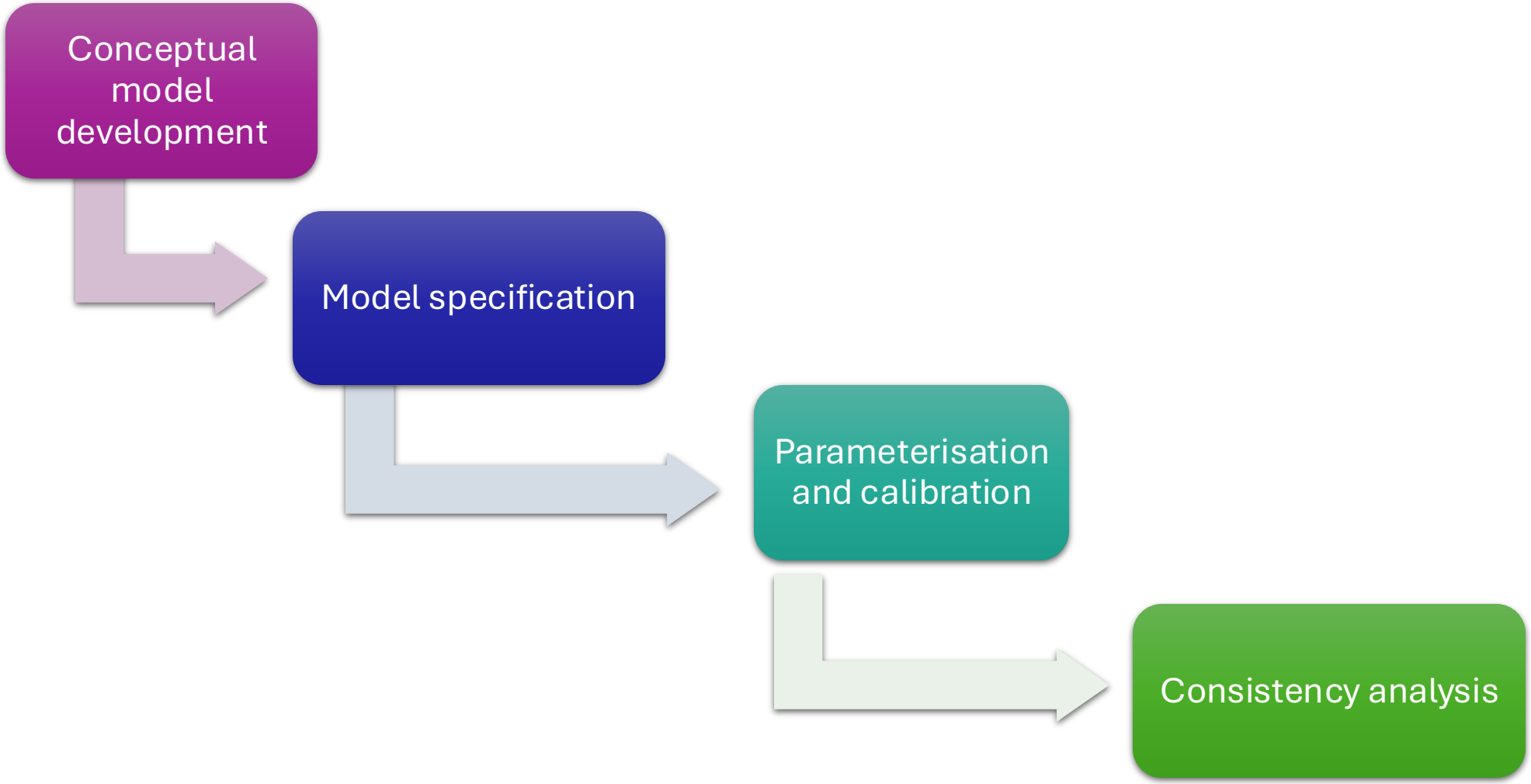
**Informing interventions to reduce inequalities in adults' leisure-time physical activity: an agent-based modelling approach**

Process being modelled:
Adults making their decision to practice leisure time physical activity

Purpose of model:
To understand the emergence of income inequalities in adults' leisure-time physical activity.

To explore what types of interventions, their mechanisms and underlying conditions could optimise efforts to reduce income inequalities in leisure-time physical activity.

# Agent-based model: Development




Jones, SM, Hunter, RF, Garcia, L. 2025. Developing a Conceptual Model for Collective Patterns and Leisure-Time Physical Activity Inequalities Among Adults

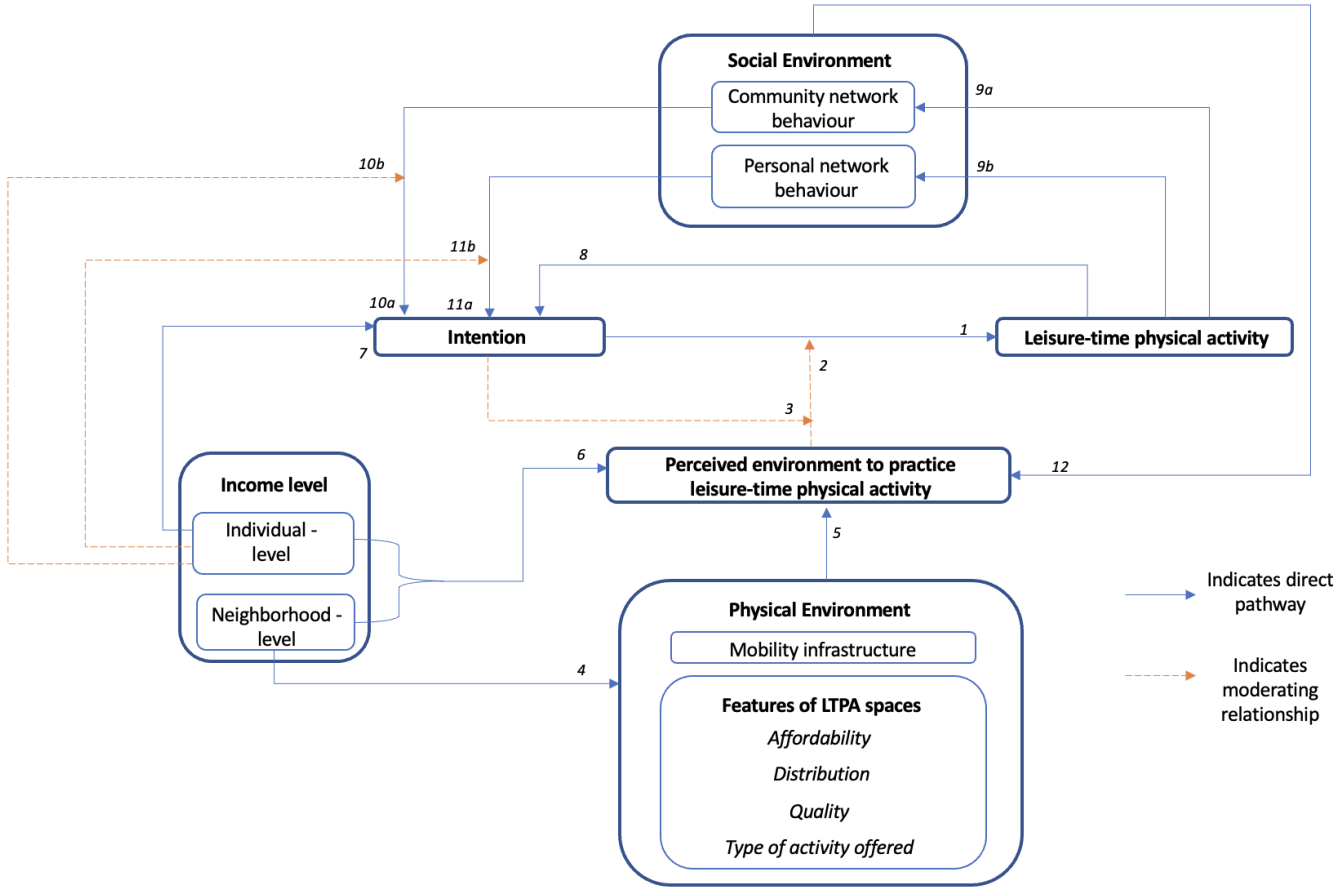
# Conceptual model development

Comprised four main stages:

1. initial development
   - Developed by research team all with expertise on PA, PA inequalities, built and social environments
2. realist reviews
   - Focusing on built and perceived environments
   - Focusing on the psychosocial influences

   (how these differ for whom, under what conditions)
3. expert consultation
   - Conducted with 40 experts
   - 80% agreement
4. final draft
   - Incorporating experts' suggestions
   - Refining with research team

# Conceptual model

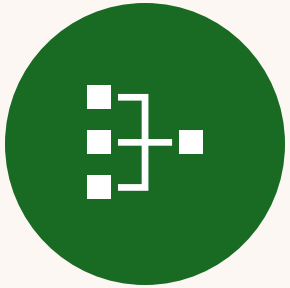



| Meanings and assumptions of the relations contained in the conceptual model. | |
|---|---|
| 1 | A person's behaviour is a function of their intention. The higher the intention for physical activity, the more likely a person is to execute the behaviour. |
| 2 | The relation between intention and behaviour is moderated by the person's perception of the environment to practice. The more positive the perception, the stronger the relationship between intention and behaviour. |

Jones, SM, Hunter, RF, Garcia, L. 2025. Developing a Conceptual Model for Collective Patterns and Leisure-Time Physical Activity Inequalities Among Adults

# Model specification

Translating the conceptual model to a suitable algorithm for the agent-based model.



Involved creating the model, initialising all agents, and model processes.

# Model calibration and testing

**Parameterisation and calibration**

- Using empirical evidence to inform model parameters.
- This ensures model output is consistent to what we experience/observe in the real world.

**Consistency analysis**

- Agent-based models are stochastic (random).
- Conducted to understand how many times we needed to run the model to get reliable outputs.

# Applications to build ABM models

- NetLogo (https://www.netlogo.org/)
- AnyLogic (https://www.anylogic.com/use-of-simulation/agent-based-modeling/)
- Mesa (https://mesa.readthedocs.io/latest/)
- Repast (https://repast.github.io/)
- Gamma (https://gama-platform.org/)
- Python, R, C++ etc.

- Antelmi et al., 2024. Reliable and Efficient Agent-Based Modeling and Simulation

# Additional resources: Journals

Journal of Artificial Societies and Social Simulation – JASSS (https://jasss.org/JASSS.html)

Journal of Simulation (https://www.tandfonline.com/journals/tjsm20)

Simulation Modelling Practice and Theory (https://www.sciencedirect.com/journal/simulation-modelling-practice-and-theory)

Environmental Modelling & Software (https://www.sciencedirect.com/journal/environmental-modelling-and-software)

PLoS Complex Systems (https://journals.plos.org/complexsystems/)

# Additional resources: Open access

- Agent-Based Modelling for the Self Learner
- The Beginner's Guide to NetLogo Programming
- Complexity Explorer
  - Various courses, including ‘Introduction to Agent-Based Modeling’ and ‘Fundamentals of NetLogo’
- Modelling Commons (library of NetLogo models)
- CoMSES Net (general ABM library and resources)

# Additional resources: Books and articles


- Railsback S, Grimm V. Agent-based and individual-based modeling: a practical introduction. 2nd ed. New Jersey: Princeton University Press; 2019.
- Wilensky U, Rand W. An introduction to agent-based modeling: modeling natural, social and engineered complex systems with NetLogo. Cambridge, MA: MIT Press; 2015.
- Badham J et al. Developing agent-based models of complex health behaviour. Health Place. 2018;54:170-7.
- Auchincloss A, Garcia L. Brief introductory guide to agent-based modeling and an illustration from urban health research. Cad Saude Publica. 2015;31(Suppl 1):65-78.
- Yang Y. A narrative review of the use of agent-based modeling in health behavior and behavior intervention. Transl Behav Med. 2019;9(6):1065-75.

# Session 1 training objectives:

1. To introduce the concepts of agent-based Modelling.

2. To highlight tools, software and core texts for using and applying agent-based models.

# Next session

1. To understand how to design and develop an agent-based model.

2. To understand how data from agent-based models can be analysed.

Short feedback survey

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# SAVE THE DATE

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Join us for a series of online short courses designed to build skills in a range of systems thinking methods for NCD prevention and control. Further details and registration links will be advertised 6 weeks in advance of the training sessions.

### Introduction to Systems Dynamics Modelling:
Wednesday 15 & 22 October 2025 10:30 – 12:30 (BST)

### Introduction to Agent-based Modelling:
Wednesday 5 & 12 November 2025 10:30 – 12:30 (GMT)

### Introduction to Soft Systems Modelling:
Wednesday 21 & 28 January 2026 10:30 – 12:30 (GMT)

### Introduction to Viable Systems Modelling:
Wednesday 18 & 25 February 2026 10:30 – 12:30 (GMT)

### Introduction to Systems Maps and Causal Loop Diagrams:
Wednesday 25 March & Wed 1 April 2026 10:30 – 12:30 (GMT)

### Introduction to Stakeholder Network Analysis:
Wednesday 22 & 29 April 2026 10:30 – 12:30 (BST)

SCAN ME

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# Thank you

For any questions contact whocc@qub.ac.uk

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